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Evaluation of four steering wheels to determine driver hand placement in a static environment

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A B S T R A C T

While much research exists on occupant packaging both proprietary and in the literature, more detailed research regarding user preferences for subjective ratings of steering wheel designs is sparse in published literature. This study aimed to explore the driver interactions with production steering wheels in four vehicles by using anthropometric data, driver hand placement, and driver grip design preferences for Generation-Y and Baby Boomers. In this study, participants selected their preferred grip diameter, responded to a series of questions about the steering wheel grip as they sat in four vehicles, and rank ordered their preferred grip design. Thirty-two male participants (16 Baby Boomers between ages 47 and 65 and 16 Generation-Y between ages 18 and 29) participated in the study. Drivers demonstrated different gripping behavior between vehicles and between groups. Recommendations for future work in steering wheel grip design and naturalistic driver hand positioning are discussed.

1. Introduction

Considering the amount of time drivers are behind the wheel, drivers' wants, needs and comfort with the steering wheel are of importance. Because of heavier traffic and congestion on roadways, average commutes are getting increasingly long. The number of commuters tripled between 1960 and 2000 (Federal Highway Administration, 2011). In 2000, 40% of commuters in metro areas traveled over 30 min to work one way, and 14% traveled over 45 min one way (Federal Highway Administration, 2011). One of the primary interactions drivers have with their car during travel time is via the steering wheel. Ideally for safety reasons, drivers should grip the wheel with two hands at all times. However, naturalistic studies have concluded that this is frequently not the case (Jonsson, 2011; Walton and Thomas, 2005). Designing a steering wheel with ideal characteristics to suit various driver populations may elicit safe driving behaviors as well as accommodate drivers with greater comfort during long commutes and short drives.

This study focused on driver impressions of steering wheel grips in order to inform steering wheel design and future research. The automotive industry has a particular interest in the Baby Boomer and Generation-Y age groups because of the current purchasing power and potential future purchasing power of these market segments, respectively (Deloitte, 2008; Healthwise, Inc., 2007). In addition, Baby Boomers face physical challenges not typical of Generation-Y, such as arthritis. Currently, approximately half of Baby Boomers suffer from arthritis, and it is projected that by 2020, there will be 26 million cases (Hootman and Helmick, 2006). Male participants from two different groups (16 Generation-Y, defined as born between 1977 and 1994, and 16 Baby Boomers, defined as born between 1946 and 1964) sat in four different production vehicles and were asked a series of questions about the grip in the vehicle. In addition, anthropometric data were collected.

1.1. History of steering wheel designs

Historically, before the steering wheel, automobiles were equipped with a steering tiller, essentially a joystick that made controlling the vehicle difficult. In 1899 the first car was fitted with a steering wheel to provide increased control and stability (Patrascu, 2010). Though power steering existed in primitive forms as long ago as 1902, it was not widely adopted into vehicle design until 1956 (Patrascu, 2010). While, some automotive companies voluntarily elected to include airbags in their vehicles in the 1970's, it was not until 1998 that air bags became mandatory on all new vehicles slated for sale in the USA, which caused a significant

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change to steering wheel design (Federal Legislation, 2013). The steering wheel served no other purpose than physically maneuvering the vehicle, accommodating the horn, and housing airbags, until the 1990s when technology in vehicles rapidly expanded and began to envelope the center console, while many of the controls began to migrate onto the steering wheel (Patrascu, 2010). Today, airbag regulations, numerous controls, and the needs of designers and engineers dictate the size and shape of the steering wheel (Patrascu, 2010). The overall design of the steering wheel has remained largely stagnate over the last century, and currently very little research is being done regarding drivers' use of and preferences in steering wheel grip design.

1.2. Current steering wheel research

1.2.1. Occupant packaging

Occupant packaging is defined as the layout of space dedicated for the driver and passengers of the vehicle, which include the seat and steering wheel positioning. With the help of past research, the Society of Automotive Engineers (SAE) has generated numerous recommended practices for occupant packaging, such as driver hand control reach, driver selected seat position, and driver's eye locations (SAE International, 2007, 2010, 2011). In 1979 Schneider, Olson, Anderson, and Post contributed to the SAE standards by identifying the variables that most affect a driver's selected position. The primary objective of Schneider et al.'s (1979) research was to measure differences between driver's selected seat position in a non-driving (static) versus driving (dynamic) condition, using 51 male and 57 female participants in six different vehicles. The authors found that the mean difference between static and dynamic adjustments was less than 1.27 cm. In other words, the findings of Schneider et al. (1979) demonstrated that static seat position accommodates the majority of a driver's seating preferences. Because of the Schneider et al. study, studies that use static seating positions have become standard practice.

In addition, Schnieder et al. used stepwise regression analysis to explain the seating variance among participants using 13 measured anthropometric values. Stature overwhelmingly explained between 32% and 62% of the variance for selected fore and aft seat position, and when adjustments were made to accommodate for height of participants, gender differences appeared to be uniform (Schneider et al., 1979).

At present, engineers consider steering wheels within the context of occupant packaging with an emphasis on anthropometric data and ergonomic principles. Moreover, engineers focus on occupant packaging to ensure the safety of drivers and passengers as well as other large aspects of the vehicle, such as wheelbase and roof height. Even though the steering wheel is one of the many aspects considered, simply including it in packaging does not ensure an adequate or desirable design. Many studies have been done to create an effective occupant package methodology (Reed et al., 1999; Vogt et al., 2005). However, simply integrating the steering wheel in the large-scale ergonomics of the vehicle does not sufficiently consider other elements of the steering wheel such as on-wheel controls, materials and grip design.

1.2.2. Naturalistic studies

Few studies have focused on drivers' hand positions on the grip of the steering wheel. An on-road observational study by Walton and Thomas (2005) revealed three different ways drivers placed their hands on the steering wheel: 1) two hands on top of the wheel, 2) one hand on top, or 3) two hands on the bottom of the wheel or off the wheel as if driving with knees. They observed drivers in eight different geographical locations and recorded the number of hands visible on the top part of the steering wheel — either zero, one, or two. The authors found that often times drivers did not grip the steering wheel at the advised “10 and 2” or “9 and 3” in real on-road situations (AAA, 2012; Walton and Thomas, 2005). Across all eight locations, approximately 25% of drivers had two hands on the lower half of the wheel, approximately 25% placed two hands on the top half of the wheel, and approximately 50% used one hand on the top half of the wheel. In the eight on-road locations, there were high, medium and low speed zones, varied traffic volume, accident zones and varied number of lanes. Walton and Thomas (2005) found that the number of hands on the top part of the steering wheel did not change based on accident zones or lane position (left versus center versus right lane) but did change with higher speeds and greater traffic volume, as drivers tended to grip the wheel with more hands.

Jonsson (2011) conducted a study observing natural hand positions of drivers while on a roadway. A researcher photographed drivers at various times and under various lighting conditions on a 70 km/h, straight roadway. From each photograph, gender, seat belt use, mobile phone use, registration number, as well as hand location on the steering wheel were recorded. Hand location was recorded in correspondence with a clock dial: 9, 10, 11, 12, 1, 2, 3. Hands below these locations were recorded as 0. Overall, data from 1,894 photographs were recorded.

Jonsson (2011) found that females and males differed significantly in hand placement position. Of the males, 38% placed the left hand on the bottom of the wheel, 55% placed the left hand between positions 9 and 12, and 20% placed the right hand between positions 3 and 12, while females were 50%, 49% and 29%, respectively. There were no significant differences between men and women for placement of the right hand on the bottom of the wheel (males = 78%, females = 71%), at least one hand on the upper half of the wheel (males = 72%, females = 61%), and both hands on the bottom of the wheel (males = 28%, females = 39%). Both hands on the bottom of the wheel were most common as compared to recorded clock positions (i.e., 9, 10, 1, 2). Jonsson (2011) also found that 18% of all drivers in the study placed both hands on the upper half of the steering wheel, which was comparable to the Walton and Thomas (2005) study that stated 25% of drivers used this hand position.

1.2.3. Simulator studies

Two studies (Imamura et al., 2008, 2009) investigated grip position and style using a driving simulator. The first study (Imamura et al., 2008) surveyed 11 participants about their grip styles and videoed their hands as they drove in a simulator. Data gathered suggested that grip positions and styles varied widely among drivers and that drivers were not necessarily aware of their grip positions and styles. The second study (Imamura et al., 2009) investigated the possibility of using sensors in the steering wheel grip as a way to measure driver behavior. A prototype of a steering wheel with sensors was developed; however, no data were presented on testing the technology with participants.

1.2.4. Grip characteristics

One study by Nishina et al. (2006) focused on user preferences regarding steering wheel grips. Twenty-one males with extensive driving experience sat in a vehicle and used seven sets of adjectives on a continuum to describe the grip of the wheel (soft/firm, elastic/stiff, fitting/non-fitting, rough/smooth, luxurious/cheap, steady/slippery, comfortable/uncomfortable). For example, “firm” was designated as 1, while “soft” was designated as 7, and “non-fitting” was 1, while “fitting” was 7. The data were analyzed utilizing the Kansei method to create a structural equation model to assess correlations and develop two models based on two distinct differences in user ratings. Both models focus on defining comfort by

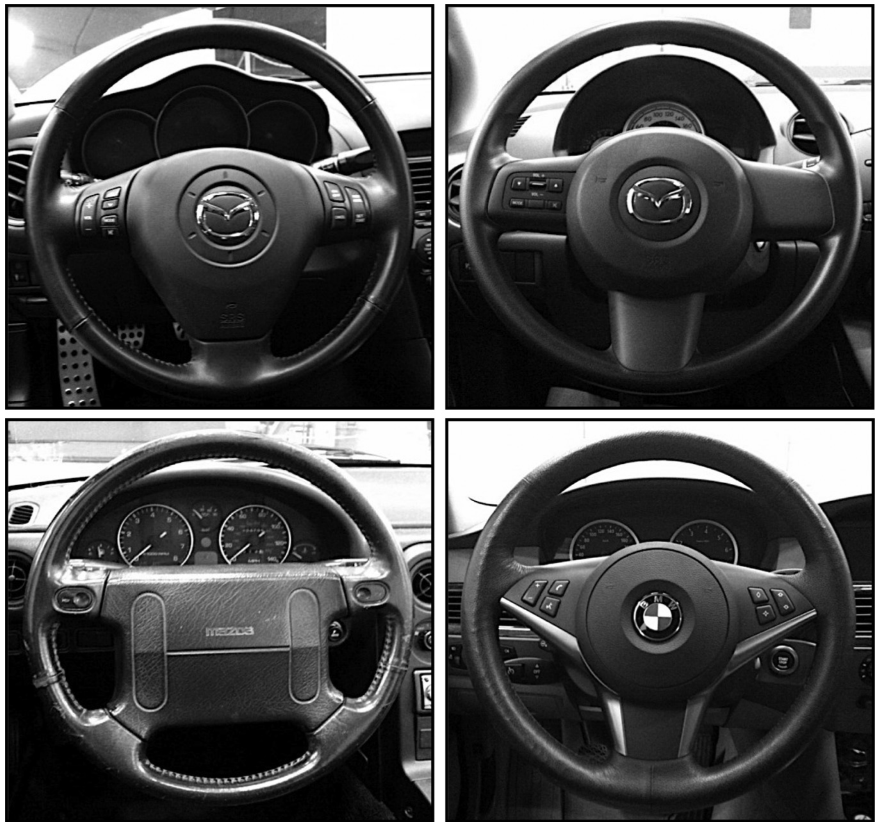

Fig. 1. Four steering wheels investigated. Clockwise from top left: 2004 Mazda RX-8, 2010 Mazda2, 2006 BMW 530xi, and 1991 Mazda Miata.

correlation strengths with the terms "fitting" and "luxurious". All other descriptors (soft, elastic, steady, dry, and rough) were based on correlations with these two terms. One model was more strongly correlated with the terms "soft/firm", while the other was more strongly correlated with the terms "elastic/stiff". Ideally, engineers could use these models to design steering wheels that meet the expectations of drivers.

With increasing attention on vehicle interiors and comfort, the steering wheel may now be a feature of interest for consumers as well as a key safety component. Generation-Y and Baby Boomers are key populations of interest for automobile manufacturers. According to a survey by NHTSA in 2009, 17.3% (approximately 36.3 million) drivers are Generation-Y, and 33.3% (approximately 70.7 million) drivers are Baby Boomers. For the youngest drivers, teenagers between 16 and 19 years, the average commute per day is 25.1 km, and teens that live in urban areas drive significantly more kilometers than teens that live in rural areas (Trowbridge and McDonald, 2008). With urbanization on the rise, this suggests a general increase in the number of kilometers driven by young drivers.

According to Coughlin (1999), a significant necessity for the future will be for society to address the increasing numbers of older adults' needs and preferences. Throughout Europe, parts of Asia, and the United States, the aging population is increasing rapidly. By 2030, the number of people in the U.S. ages 65 and older will be nearly double that of the year 2000 (U.S. Census, 2000). Currently, 80% of the 36 million adults over 65 years are driving (Federal Interagency Forum on Aging Related Statistics, 2008). Thus, special considerations for aging drivers should be incorporated into vehicle designs. With time spent in vehicles on the rise and the aging driver population increasing, using best practice automotive design becomes paramount, particularly for the most frequently manipulated features such as the steering wheel.

The aim of the current study was to examine driver interactions with steering wheels in various vehicles by using anthropometric data, driver grip location, and driver preferences for two groups, Generation-Y and Baby Boomers.

2. Material and methods

2.1. Participants

Participants consisted of two age groups of licensed drivers: 16 male Baby Boomers (47–65 years old, $M = 55$, $SD = 5.89$) and 16 male Generation-Y (18–29 years old, $M = 25$, $SD = 2.03$). All participants had a minimum of two years of driving experience to ensure that they had sufficient skill in manipulating steering wheels in vehicles. Participants were paid \$20 to \$25 based upon the time it took to complete the study with a maximum duration of three hours. All participants provided informed consent.

2.2. Materials

For this study, four production vehicles were used – a 1991 Mazda Miata sports car, a 2004 Mazda RX-8 sports car, a 2006 BMW 530xi luxury sedan, and a 2010 Mazda2 economy sedan. See Fig. 1. The vehicle selection provided a broad stratification of vehicle classification covering older and newer design as well as economy versus luxury design. Based on AutoPacific's New Vehicle Satisfaction Survey, from years 2010–2013, male buyers accounted for an average 77% of the BMW 5-series purchases, 62% of the Mazda2 purchases, and 67% of the Mazda MX-5 (previously called Miata) purchases. Comparable data were only available for the Mazda RX-8 in 2011, where 80% were male buyers. In addition, the age demographics selected for this study represent over 52%, 61%, and 58% of the 2010 to 2013 purchases for the BMW 5-series, Mazda2, and

Mazada MX-5, respectively, and 51% of purchases for the Mazda RX-8 in 2011 (AutoPacific, New Vehicle Satisfaction Survey, 2013). Therefore, the four vehicles used in the current study represent not only a broad range of vehicle classification but also specific models that the participant demographics tend to purchase.

This study sought to understand driver grip placement in various production vehicles by allowing drivers to behave as they would without outside influence. This means that participants were allowed to select their own seating position, and the vehicles were not modified in any way. All vehicles had similar black interiors and manual transmissions. The BMW 530xi and Mazda RX-8 had leather-wrapped steering wheels, while the Mazda2 and Mazda Miata had simulated leather grips. The Mazda RX-8, Mazda2 and Mazda Miata grip sizes were 2.78 cm in diameter, while the BMW 530xi's grip diameter was 3.25 cm. Of the four cars, the 2004 Mazda RX-8 and 2010 Mazda2 had manual tilt steering wheels, which were adjusted via levers on the steering column; the 1991 Mazda Miata had no steering wheel adjustment; the BMW 530xi had a power tilt and telescoping, adjusted via a small joystick on the steering column. Also, all vehicles had front to rear seat adjustments. The BMW 530xi and Mazda RX-8 had power, vertical seat adjustments.

Other materials utilized to collect data included: seven pairs of wooden dowels ranging from 2.2 cm to 5.1 cm (2.2, 2.5, 2.9, 3.2, 3.8, 4.4, 5.1 cm) in diameter and photos of the steering wheels from the four study vehicles.

2.3. Procedure

After participants provided consent and demographic data were collected, the researchers asked the participant to grasp seven pairs of various sized wooden dowels (one in each hand) to obtain grip diameter size preferences. Five hand measurements as defined in Greiner (1991) were obtained: digit 3 length, palm length, digit 3 height, hand breadth, and digit 1 link length. See Fig. 2.

The order in which the participants interacted with the vehicles was counterbalanced to avoid confounds from order bias. Participants were instructed to sit in the driver's seat of the vehicle and adjust the seat and steering wheel to a comfortable position, while the researcher sat in the front passenger seat. The participants were asked to take a moment to become familiar with the car and steering wheel and then place their hands on the steering wheel in the most comfortable position. Hand placement was recorded on a spreadsheet by placing dots on a steering wheel outline, which corresponded with the participant's grip position. Next, each participant completed seven items about the steering wheel grip. The items from Nishina et al. (2006) were used (soft/firm, pliable/stiff, fitting/non-fitting, rough/smooth, luxurious/cheap, steady/slippery, comfortable/uncomfortable) and were rated on a 7-point Likert scale. One sample item was, "On a scale of 'luxurious' being 1 and 'cheap' being 7, how would you rate the steering wheel grip?" Next, each participant was asked to imagine two different driving scenarios (driving on a 5-h highway road trip at 112.7 km/h and driving while stuck in city traffic for an hour) and rate the comfort of that particular steering wheel using a 1-7 scale, where 1 = *very comfortable* and 7 = *very uncomfortable*. Finally, the participant was asked to rank grip preferences based on photos of the four vehicles' steering wheels. The "most comfortable" steering wheel grip was ranked one, while the "least comfortable" was ranked four.

3. Results

3.1. Calculation

Driver preference was assessed by combining driver hand placement and anthropometric data. In past studies that investigated driver hand placement in a naturalistic setting, no anthropometric data were measured. Anthropometric data were compared between groups using t tests ($\alpha = 0.05$) and trends found by using correlations. Driver hand placements were assessed qualitatively by overlaying translucent markers and then categorically to assess common locations. Hand placement was compared across vehicles and groups with descriptive data, using the same categories as Jonsson's study (2011). Drivers with atypical hand placement were grouped and compared to typical hand placement with t tests.

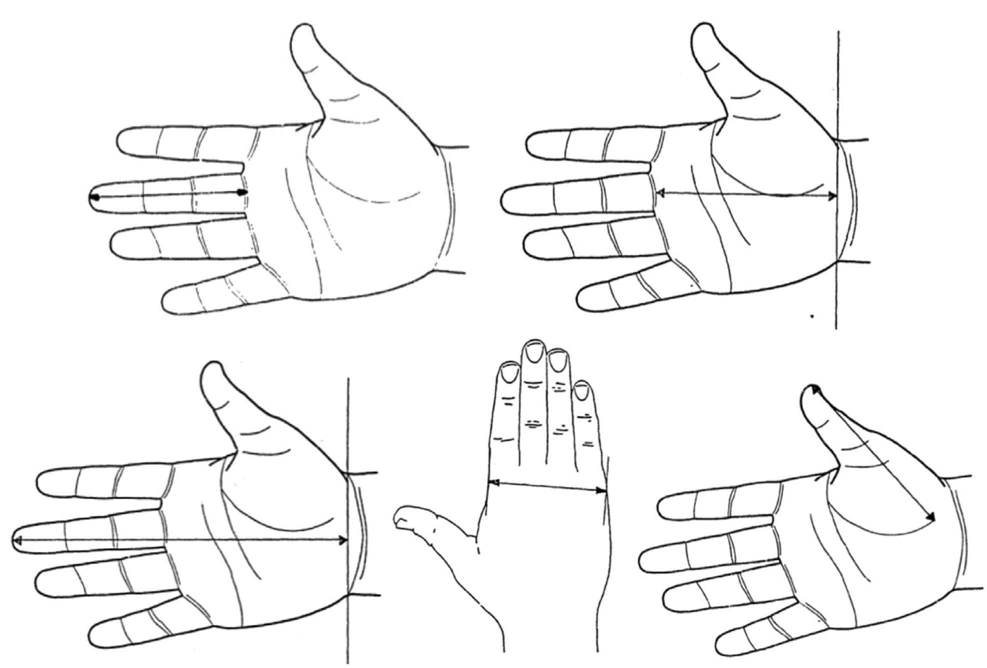

Fig. 2. Hand measurements used. Top row: digit 3 length, palm length. Bottom row: digit 3 height, hand breadth, and digit 1 link length.

Grip design was assessed using rank orders of the four steering wheels, and Likert scales were correlated between groups and between vehicles. It should be noted that when testing for mean differences using the T or F statistic, if homogeneity was violated, the Satterthwaite approximation was used.

3.2. Driver behavior

3.2.1. Anthropometric data

To compare the Baby Boomers and Generation-Y groups, independent samples t tests were conducted on the participants' hand measurements, body height, and preferred dowel size. The results showed no statistically significant differences on any of the five hand measurements, body height, or dowel size. Because there were no significant differences between groups for the hand measurements and body height, the groups were combined, and a correlation matrix was calculated to examine relationships between the hand and body height measurements and dowel size preference. See Table 1. No significant correlations were found between hand measurements and dowel size preference. However, many of the hand measurements were correlated with body height. Body height was significantly correlated with dowel size, $r = 0.359$, $p < 0.05$. Notably, the most frequently preferred dowel size was 3.175 cm; 18 participants selected this size. Seven participants chose the 3.81 cm diameter dowel; four chose 2.8575 cm; two chose 4.445 cm; one chose 2.54 cm; and none chose 2.225 cm or 5.08 cm.

3.2.2. Driver hand placement

For the data where participants were asked to grip the steering wheel in the most comfortable location during the in-vehicle segment of the study, each data point (i.e., dot) was made translucent and overlaid onto a common background. See Fig. 3.

A total of five participants (3 Generation-Y, 2 Baby Boomer) indicated in at least one vehicle that the most comfortable way to grip the steering wheel was with only one hand. Of these five participants, three used one hand on more than one vehicle. Table 2 highlights the percentage of several grip locations across both groups and all vehicles. Five (3 Generation-Y, 2 Baby Boomer) of the 32 participants used an asymmetrical hand arrangement on at least one vehicle. Two of those five had an asymmetrical hand arrangement on more than one vehicle. One participant used both asymmetrical and one-handed grip arrangements. Five participants (3 Generation-Y, 2 Baby Boomer) gripped the steering wheel on the lower half at least once. All five of these gripped the wheel on the lower half in more than one vehicle. (One of these participants used a mixed configuration where one hand was on the top of the wheel and the other on the bottom of the wheel where the left hand was on the lower half of the wheel and the right hand on the top half.)

Participants who exhibited any of the atypical hand placement locations ($n = 12$) were separated into one group and compared to participants who placed both hands, symmetrically, on the top of the steering wheel ($n = 20$). Hand measurements, body height and dowel size preference were compared between groups. Neither the hand measurements nor dowel size preferences were significantly different between groups, but body height was significantly different, $t(27.78) = -2.285$, $p < 0.05$. Participants who gripped the steering wheel in a manner that was not symmetrical and on the top part of the wheel were significantly shorter ($M = 177.28$ cm) in body height than participants who gripped the wheel symmetrically on top ($M = 181.74$ cm).

3.3. Grip design preferences

3.3.1. Rank orders

Referencing photographs of vehicle steering wheels, participants were asked to rank order the steering wheels from most preferred (1) to least preferred (4). See Table 3. Generation-Y participants ranked the Mazda RX-8 as first preference (38%) more than Baby Boomers (6%). Baby Boomers ranked the BMW 530XI as first preference (81%) more than Generation-Y participants (56%). There were no significant differences between the Generation-Y and Baby Boomer groups for all other rankings.

3.3.2. Likert scales

Vehicle steering wheels were compared using the seven Likert scale ratings (soft/firm, pliable/stiff, fitting/nonfitting, etc.) between groups (Generation-Y and Baby Boomers). Generation-Y ranked the BMW 530XI as more *cheap* than Baby Boomers, $t(30) = 2.181$, $p < .05$ (Baby Boomers $M = 2.19$, Generation-Y $M = 3.31$). Generation-Y ranked the Mazda Miata as *smoother* than Baby Boomers, $t(27.287) = 2.110$, $p < 0.05$ (Baby Boomers $M = 4.33$, Generation-Y $M = 5.56$). Generation-Y ranked the Mazda2 as more *soft* than Baby Boomers, $t(30) = -2.374$, $p < .05$ (Baby Boomers $M = 6.06$, Generation-Y $M = 4.94$). There were no significant differences between groups for the Mazda RX-8. Correlations between Likert scale rankings for each car and each group are shown in Tables 4a through 4d.

4. Discussion

The aim of the current study was to examine driver interactions with production steering wheels in four vehicles by using anthropometric data, driver hand placement, and driver grip design preferences for Generation-Y and Baby Boomers. Results of the current study were in line with previous studies in the literature and provide additional insight regarding driver comfort and behavior. Considerations for steering wheel grip design, driver grip behavior, and future research directions are discussed.

Table 1
Anthropometric correlations with Baby Boomer and Generation-Y group combined.

	Range (cm)	Mean (cm)	Std Div (cm)	Digit 3 length	Palm length	Digit 1 link length	Hand breadth from digitizer	Digit 3 height	Dowel	Height
Digit 3 length	1.8	8.47	0.46	1						
Palm length	2.2	10.94	0.59	0.382[a]	1					
Digit 1 link length	3.5	11.93	0.89	0.595[b]	0.445[a]	1				
Hand breadth from digitizer	1.7	9.47	0.38	0.071	0.512[b]	0.131	1			
Digit 3 height	3.7	19.41	0.88	0.787[b]	0.871[b]	0.612[b]	0.412[a]	1		
Dowel	1.9	3.33	0.44	0.268	0.162	0.009	0.122	0.264	1	
Height	25.4	180.06	6.67	0.642[b]	0.394[a]	0.607[b]	0.130	0.602[b]	0.359[a]	1

[a] $p < .05$.
[b] $p < .01$.

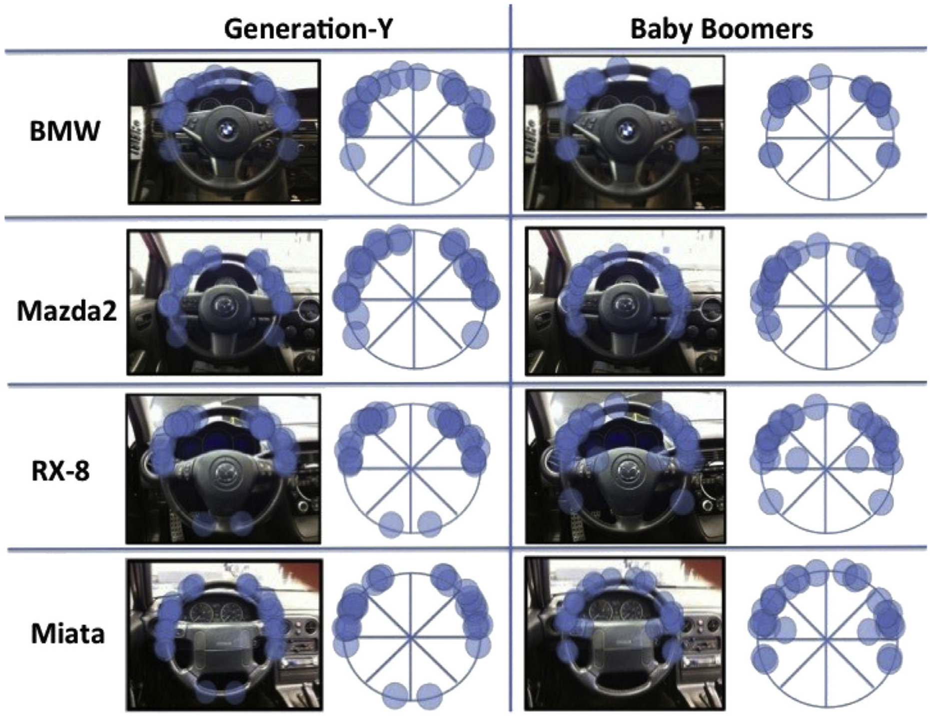

Fig. 3. Driver grip locations.

4.1. Driver hand placement

In this study most people believed that the most comfortable position to grip the steering wheel was symmetrically (75.8%) and/or on the top half of the steering wheel (79.7%), while only 10.9% reported that two hands on the bottom of the wheel would be most comfortable. These percentages were significantly larger than those found in Jonsson (2011), 6–12% symmetrical and 28–39% two hands on the lower half. This may be due to the fact that drivers estimate a comfortable position in a static environment differently than in a dynamic environment, or they may be quite unaware of where they place their hands while driving.

The participants who gripped the wheel non-symmetrically, one handed, or on the bottom of the wheel, were significantly shorter in body height than those who indicated that gripping the wheel on the top symmetrically would be comfortable. It is possible that abnormal behavior may be due to non-optimal relationship between the vertical seat adjustments and vertical steering wheel adjustments for shorter individuals. This may be in line with Jonsson's study (2011) which found that females tended to place both hands on the lower half of the wheel when driving, as females tend to have a shorter body height than males (Kroemer et al., 1994).

Table 2
Percentages of specific hand positions across all vehicles for both age groups.

	BB[a]	GenY[b]	Total
Right hand on the bottom of the wheel	0%	0%	0%
Left hand on the bottom of the wheel	0%	1.6%	0.7%
Left hand between 9 and 12	12.5%	6.3%	9.4%
Right hand between 3 and 12	0%	3.1%	1.6%
At least 1 hand on the upper half of the wheel	93.8%	87.5%	90.6%
Symmetric position (i.e. 10 and 2)	70.3%	81.3%	75.8%
Both hands on upper half	81.3%	78.1%	79.7%
Both hands on the bottom half	12.5%	9.4%	10.9%

[a] BB: Baby Boomer.
[b] GenY: Generation-Y.

4.2. Grip design

Anthropometric data (digit 3 length, palm length, digit 3 height, hand breadth, digit 1 link length, body height, and dowel size preference) showed no significant difference between groups. However, there was a significant correlation between body height and preferred dowel size, $r = 0.470$, $p = 0.007$. The majority, 56% of participants, preferred the 3.175 cm dowel size. Three of the four cars used in this study have steering wheels with 2.75 cm diameters and one with 3.25 cm. The preferred size, 3.175 cm, lies between the two sizes in this study. While 3.175 cm was commonly selected, in significantly taller or shorter populations, it may be appropriate to use a steering wheel with a larger or smaller diameter. Steering wheel manufacturers ought to consider the expected body height range of their target market to decide on an appropriate grip size. Creating a grip of appropriate diameter for drivers may provide comfort without causing additional muscle strain.

Nishina et al. (2006) created a rigid model of grip characteristics based on a single steering wheel design. The current study shows that this model may vary by age group and may not be applicable to all vehicles. See Tables 4a through 4d. Likert scale correlations were different among cars and between age groups. While the Nishina et al. (2006) model is a foundation for understanding driver

Table 3
Rank order preferences for Generation-Y and Baby Boomer groups by vehicle.

Rank	BMW 530XI		Mazda RX-8		Mazda2		Mazda Miata	
	GenY[b]	BB[a]	GenY	BB	GenY	BB	GenY	BB
1	56%	81%	38%	6%	–	–	6%	6%
2	38%	6%	38%	63%	19%	19%	6%	6%
3	–	6%	25%	25%	38%	50%	38%	13%
4	6%	–	–	–	44%	25%	50%	69%

[a] BB: Baby Boomer.
[b] GenY: Generation-Y.

Table 4a
Correlations of Likert scale terms for Generation-Y and Baby Boomer groups for the Mazda Miata.

		Baby Boomers						
		Mazda Miata						
		Soft/firm	Pliable/stiff	Fitting/nonfitting	Rough/smooth	Luxurious/cheap	Steady/slippery	Comfortable/uncomfortable
Generation-Y	Soft/firm	1	0.511	0.182	0.068	**0.580**[a]	−0.049	0.291
	Pliable/stiff	0.307	1	0.391	−0.08	0.157	0.091	**0.531**[a]
	Fitting/nonfitting	−0.424	0.285	1	0.276	0.337	0.223	0.401
	Rough/smooth	0.115	0.113	0.279	1	0.241	**0.681**[b]	0.36
	Luxurious/cheap	0.25	0.318	−0.055	−0.146	1	0.101	0.059
	Steady/slippery	−0.311	−0.061	0.181	0.221	−0.044	1	0.297
	Comfortable/uncomfortable	−0.444	0.455	**0.556**[a]	−0.035	0.268	**0.506**[a]	1

[a] $p < .05$.
[b] $p < .01$.

Table 4b
Correlations of Likert scale terms for Generation-Y and Baby Boomer groups for the Mazda RX-8.

		Baby Boomers						
		Mazda RX-8						
		Soft/firm	Pliable/stiff	Fitting/nonfitting	Rough/smooth	Luxurious/cheap	Steady/slippery	Comfortable/uncomfortable
Generation-Y	Soft/firm	1	**0.695**[b]	0.323	−0.1	0.332	−0.426	**0.551**[a]
	Pliable/stiff	−0.013	1	0.081	0.016	0.368	−0.483	0.372
	Fitting/nonfitting	0.379	−0.028	1	0.059	0.133	0.329	0.378
	Rough/smooth	−0.134	0.323	0.107	1	0.494	0.297	−0.168
	Luxurious/cheap	0.022	−0.08	0.337	0.085	1	0.229	0.144
	Steady/slippery	−0.268	**0.617**[a]	0.143	0.403	0.006	1	−0.191
	Comfortable/uncomfortable	0.396	0.025	**0.908**[b]	−0.151	0.431	0.07	1

[a] $p < .05$.
[b] $p < .01$.

wants and needs for steering wheel grips, it should be validated on several steering wheel designs and populations. Determining what is most important to drivers in grip design can greatly impact driver comfort and possibly driving behavior.

The "fit" of the wheel is important to comfort. For Generation-Y, the drivers' perception of the "fit" of the wheel was correlated with the comfort of the grip in three of the four vehicles: BMW 530xi, Mazda Miata, and Mazda RX-8. Generation-Y as well as the Baby Boomers rated the Mazda RX-8 as the most fitting. The least fitting car for both groups was the Mazda Miata. The Mazda Miata and Mazda RX-8 cars had grips that were the same diameter but different shapes, which indicate that both the shape and diameter are important to grip design and should be carefully considered in the design process.

5. Conclusion

This static study showed that Baby Boomers and Generation-Y males tend to grip the steering wheel symmetrically on the upper half of the wheel. However, this does not coincide with findings from Walton and Thomas (2005). More participants in this study gripped the steering wheel with two hands on the top half of the wheel than in the naturalistic, dynamic study where participants tended to use one hand on top of the wheel or two hands on the bottom. This discrepancy may indicate that user testing during the design process should be done in both static and dynamic environments. Also, when modeling occupant packaging, grip behaviors in both static and dynamic environments should be used. Testing in both environments would lead to a better design that accounts for user behavior in a variety of scenarios.

This study provides the platform for a variety of subsequent studies. Future work in this area would benefit from continued research that includes female populations and additional age groups, such as Generation-X. In addition, validating Nishina et al. (2006) model of grip characteristics could be of particular interest to designers and engineers in automotive interior design. The relationship between driver grip behavior in the vehicles users currently own and behavior in unfamiliar vehicles could further

Table 4c
Correlations of Likert scale terms for Generation-Y and Baby Boomer groups for the BMW 530xi.

		Baby Boomers						
		BMW 530xi						
		Soft/firm	Pliable/stiff	Fitting/nonfitting	Rough/smooth	Luxurious/cheap	Steady/slippery	Comfortable/uncomfortable
Generation-Y	Soft/firm	1	**0.583**[a]	0.357	−0.143	0.056	−0.008	0.167
	Pliable/stiff	**0.612**[a]	1	0.074	−0.022	−0.005	−0.008	−0.031
	Fitting/nonfitting	**0.574**[a]	**0.530**[a]	1	**−0.507**[a]	**0.612**[a]	−0.165	0.43
	Rough/smooth	−0.409	−0.425	−0.183	1	−0.222	**0.617**[a]	−0.441
	Luxurious/cheap	0.233	0.231	0.292	−0.493	1	0.152	**0.741**[b]
	Steady/slippery	0.444	0.352	0.456	−0.323	0.275	1	−0.067
	Comfortable/uncomfortable	0.329	0.319	**0.628**[b]	**−0.512**[a]	**0.707**[b]	0.212	1

[a] $p < .05$.
[b] $p < .01$.

Table 4d
Correlations of Likert scale terms for Generation-Y and Baby Boomer groups for the Mazda2.

		Baby Boomers						
		Mazda2						
		Soft/firm	Pliable/stiff	Fitting/nonfitting	Rough/smooth	Luxurious/cheap	Steady/slippery	Comfortable/uncomfortable
Generation-Y	Soft/firm	1	**0.520**[a]	−0.073	−0.014	0.058	−0.173	−0.05
	Pliable/stiff	0.128	1	−0.266	0.414	−0.262	−0.136	0.048
	Fitting/nonfitting	0.26	−0.041	1	**−0.578**[a]	0.419	0.169	0
	Rough/smooth	−0.351	0.007	**−0.508**[a]	1	−0.476	0.244	−0.14
	Luxurious/cheap	0.147	0.258	0.14	**−0.583**[a]	1	0.192	0.413
	Steady/slippery	−0.222	0.161	−0.055	0.014	0.412	1	0.278
	Comfortable/uncomfortable	−0.15	0.132	0.187	−0.177	0.463	0.464	1

[a] $p < .05$.

inform future steering wheel designs. Future experimental studies could also explore more controlled variables such as participant grip position in a single car with a variety of steering wheels. Additionally, future studies should address dynamic driving situations in a closed experimental field or simulator study with one car and a variety of steering wheels. These studies would lend more in-depth understanding to participants' chosen grip position as well as dynamic inputs with those positions.

While this study was an initial, exploratory study, findings did show some trends in grip behaviors among the participants. It should be noted that automotive steering wheel design could benefit from the application of the concept of affordances, which states that beings gather information about their surrounding environment by directly perceiving information offered by any physical object (Gibson, 1979). Affordances are physically and intrinsically scaled to the being. For example, for an adult, a stair with its flat, supportive surface and height affords stepping or is "stepable", but for a child, the stair has a different affordance. The surface is still flat and supportive, but the height as perceived by a child now means that the stair affords climbing or is "climbable". Because of variations in biomechanics of drivers, the steering wheel may be "graspable" in different locations. Hence, incorporating affordances into steering wheel design could influence the user-steering wheel interaction and relationship, for example hand location.

Research further investigating driver grip behavior in active, on-road environments should be continued. Drivers may be largely unaware of their grip behavior while driving or change what they value for comfort in design in a naturalistic driving environment, so testing in a dynamic environment is crucial. Incorporating a grip with pressure sensors would allow for grip location mapping in a dynamic environment, as in Imamura et al. (2009). A driving simulator would give designers and engineers a better idea of how steering wheels should be designed based on driving behavior in a naturalistic setting while controlling key variables like those identified in Walton and Thomas (2005).

An accurate picture of driving behavior in realistic on-road environments may also impact the current approach in crash testing. Jonsson (2011) noted that crash test dummies are positioned in vehicles with their hands at the "10 and 2" position. Because many drivers do not hold their hands at this position while driving, a hand position that better reflects the way drivers behave in their vehicle may give a better assessment of injuries in crashes. While research associations like AAA make recommendations for driver grip position, these recommendations have been changed from the original "10 and 2" to a revised "8 and 4" position (AAA, 2012). Based on past dynamic research and this study, this "8 and 4" position coincides more closely with actual driver behavior. However, automotive manufacturers may want to consider designing steering wheels to encourage this behavior, and crash testing should be adjusted to reflect drivers' behavioral tendencies in dynamic environments. Crash testing that reflects actual driver behavior may provide more accurate insight into injuries that may occur in a crash and create a platform for better designs in future vehicles.

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